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► **To cite this version:**

Faisal Amlani. High-order explicit PDE solvers using trigonometric interpolations of non-periodic functions (with applications to engineering, geophysics, & medicine). 16th World Congress on Computational Mechanics and 4th Pan American Congress on Computational Mechanics (WCCM-PANAM 2024), Jul 2024, Vancouver (BC), Canada. hal-04688757

HAL Id: hal-04688757

<https://hal.science/hal-04688757v1>

Submitted on 13 Sep 2024

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HIGH-ORDER EXPLICIT PDE SOLVERS USING TRIGONOMETRIC INTERPOLATIONS OF NON-PERIODIC FUNCTIONS (WITH APPLICATIONS TO ENGINEERING, GEOPHYSICS, AND MEDICINE)

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ABSTRACT

This contribution presents recent developments of a Fourier series-based methodology for the numerical analysis of parabolic and hyperbolic partial differential equations (PDEs) with complex boundary conditions. Such a framework is based on a discrete "extension" approach for the high-order trigonometric interpolation of a non-periodic function (i.e., mitigating the notorious Gibb's "ringing" effect), where the ultimate goal is to build high-performance, FFT-speed, dynamic PDE solvers on general (structured, curvilinear) geometries that can provide stable and efficient resolution while faithfully preserving the dispersion/diffusion characteristics of the underlying continuous operators.

In particular, the algorithms presented here extend the class of such methods (known as "Fourier continuation") to encompass variable-coefficient 3D systems, general (curved) 3D domains, 3D parallelization, Neumann-like (e.g., traction or convective flux) boundary conditions, nonlinear/nonstationary (ODE-governed) coupling (e.g., dynamic OD-coupling), and applications to higher-order PDEs with multiple boundary conditions (e.g., Lagrangian mechanical formulations). The resulting solvers enjoy a number of desirable properties for scientific computation: accuracy by means of relatively coarse discretizations; little-to-no numerical dispersion or diffusion errors; mild (linear) CFL constraints on (explicit) time integration; and efficient parallelization for distributed-memory high-performance computing.

With an eye towards mutual validation of both simulation and experiment, the efficacy of the current state of these tools is demonstrated in the context of some of the collaborative scientific problems that have inspired them, including those in engineering (ultrasonic non-destructive testing and seismic wave propagation [1]), geophysics (seismogenic tsunamis [2]), and medicine (fluid-structure hemodynamics [3, 4], dye diffusion [5, 6]). Performance studies and comparisons to other solvers are additionally presented.

- [1] Amlani & Bruno, Journal of Computational Physics 307 (2016)
- [2] Amlani, et al., Geophysical Journal International 230 (2022)
- [3] Amlani & Pahlevan, Journal of Computational Physics 405 (2020)
- [4] Aghilinejad, et al., American Journal of Physiology - Heart & Circulatory Physiology 325 (2023)
- [5] Amlani, et al., Journal of Computational Physics 493 (2023)
- [6] Bilgi, et al., Annals of Biomedical Engineering 51 (2023)